Roman Gold Washing as Described by Pliny the Elder

exarc.net/issue-2021-3/at/roman-gold-washing-described-pliny-elder

Persistent Identifier
https://exarc.net/ark:/88735/10588
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EXARC Journal Issue 2021/3

As part of a four-year interdisciplinary research project of a Roman gold mine in the landscape known as the "Karth" to the south of Vienna, Austria, a reconstruction of gold washing took place as described by Pliny the Elder in book 33 of his Natural History. So far, the "Karth" is the only proven Roman gold mine known in the Eastern Alps. Random finds, such as fibulae and coins, suggest dating the site to the 2nd and 3rd centuries AD (Cech et al., 2013, pp.32-71; Lang et al., 2010). The following people are involved in the project: Project manager and archaeology: Brigitte Cech (independent researcher, Vienna), survey and cartography: Frank Stremke (Bremen), Roman history: Andras Hofeneder (University of Vienna), geophysical prospection: Robert Scholger (Mining University, Leoben), geology: Günther Weixelberger (Pitten), analysis of gold: Simone Elmer, Frank Melcher (Mining University, Leoben), laser ablation of gold samples: Nicole Lockhoff (Curt-Engelhorn-Centre of Archaeometry, Mainz), hydraulic engineering: Martin Fuchs (Firma Afry, Vienna), pollen analysis: Klaus Oeggl (University of Innsbruck), mapping of leats: Thomas Fleck, Nadine Riegler, Markus Foidl (Weibnitz), gold washing/panning: Heimo Urban (Graz), documentary film: Rick Spurway (Sopron). The project is financed by the Austrian Science Fund (FWF project 30790-G25).

Topography and geology of the Karth

The *"Karth"* is the local name of a hilly landscape about 70 km south of Vienna. It is bordered to the north by the Wiener Becken, to the east by the valley of the Pitten, to the south by the valley of the Hassbach and to the southwest by the Syhrngraben (See Figure 1).

Here the Romans mined a secondary deposit called the Loipersbach Formation, in which flakes of gold are randomly distributed. Secondary deposits, also called placer deposits, are the result of the erosion of primary deposits. This formation consists of reddish to reddish-brown clay and scree (mainly quartz, quartzite, and vein quartz). The deposit lies on top of a basement complex of mica schist, Semmering-quartzite, and carbonite. Research into the location of the primary deposit is still ongoing.

The remains of Roman gold mining

Since there are no veins to follow in a placer deposit and the gold is randomly distributed, underground mining with galleries and shafts is not possible. So, the Romans, who were brilliant engineers, invented hydraulic mining, a method by which the deposit is eroded by the power of water. Pliny the Elder, who died during the eruption of Vesuvius in 79AD, was procurator of the Roman province of Hispania Tarraconensis between 72AD and 74AD. As such, he was responsible for the finances of the province, also for precious metal mining. Northwestern Spain, with its many gold mines, was part of his territory. In the 33rd book of his Natural History, Pliny describes hydraulic mining from first-hand experience (Plin. NH, 33, pp.76-78, In: Bird, 2004, p.59). Aqueducts, which are known as "leats" in a mining context, were built to conduct water to large tanks above the deposit. After the surface of the deposit was cleared of vegetation and overburden, the sluice gates of the tanks were opened, and water was led over the deposit to erode it. Most of the secondary gold deposits found in Northwestern Spain consist of a hard conglomerate. In order to break this up, galleries and shafts were dug through which water was channelled. The sediment accumulated at the bottom and was washed to obtain the gold. The most famous of these Roman gold mines is Las Médulas in the province of Léon (See Figure 2) (López, 2005; Sánchez-Palencia, et al., 1999). Another well-known gold mine of this type is at Dolaucothi in Wales (Burnham and Burnham, 2004; Lewis, 1977).

Since the *"Karth"* was never used for agriculture and is heavily forested, remains of Roman gold mining are exceptionally well preserved. Five leats of a total length of about 122 km leading to the individual mining areas with their tanks have been discovered. So far, seventeen large tanks and numerous smaller tanks have been documented. The mining area, together with the catchment area of the leats, covers an area of approximately 130 km2 (See Figure 2).

The mining areas are characterised by steep, heavily eroded gullies (See Figure 3) with large tanks at the top, the largest measuring approximately 80 by 44 m. Each tank has one inlet for the leat and one or more outlets towards the mining area. Today, the walls of the tanks are preserved nearly at their original height (See Figure 4). The leats begin at a brook or river and follow the contour of the valleys with a consistent low gradient, collecting additional water from streams *en route* until they arrive at the tanks. In many parts, they can still be seen as well-preserved channels (Cech, et al., 2019) (See Figure 5).

Gold washing, according to Pliny the Elder

Pliny describes washing the sediment obtained through hydraulic mining as follows:

"*Even now there is another task on the level ground. Ditches are dug out – they call them agogae – through which the torrent of water can flow, and then they are strewn at intervals with ulex. This bush is like rosemary, rough and able to catch the gold. The sides [of the agogae] are enclosed with boards and the channels are supported over broken ground. Thus, the earth flowing onwards slides away into the sea, and the shattered mountain is washed away. …. The debris which is removed*

with great effort in the previous method, so that it does not choke the shafts, in this [method] is carried away by water. … The ulex is dried, burned and its ash washed over grassy turf so that the gold settles" (Plin. NH, 33, pp.76-78, In: Bird, 2004, p.59).

Ulex has often been interpreted as gorse (*ulex europaeus*), which is a woody, evergreen shrub with long, sharp and spiky, thorn-like leaves that can grow up to a height of up to two metres. It is, however, more probable that Pliny means heather (*calluna vulgaris*), an evergreen bush with lots of tiny leaves, but no sharp thorns. The lack of thorns is important, considering it has to be handled frequently during gold washing. Furthermore, it is an abundant native plant of Northwestern Spain and the *"Karth"* (See Figure 6).

Before discussing Pliny's description of gold washing, it is necessary to describe how a modern sluice-box for gold washing works. It is mostly metal, and the bottom is covered with a rough mat made of plastic, called miners' moss. This is fixed to the sluice-box by a metal grid and riffles (See Figure 7). The grid and the riffles create turbulences that help to dissolve the sediment and form barriers behind which the gold can accumulate. The angle at which the sluice-box is mounted depends on the amount of available water and the quantity of material to be washed. The stream of water flowing over the sluice-box causes gold and other heavy minerals, the so-called black sand, to be deposited along the riffles and the grid, as well as in the mat. In our case the black sand consists mainly of ilmenite, magnetite, and garnet with a density of 3.5 to 5.2 g/cm3 and gold with a density of 19.3 g/cm3 (Elmer, 2020, p.38). Lighter particles are swept away. Without the mat, grid, and riffles, the friction at the bottom of the sluice-box would not be strong enough to retain the black sand and the gold, and everything would be swept away. Figure 8 shows the three largest pieces of gold found so far in the *"Karth"*.

The sluice-box, as described by Pliny, functions like a modern sluice-box. He describes stationary channel-like sluice-boxes sunk into the ground with only the sides reinforced by wooden boards. These boards prevent the water from eroding the sides of the channel. If the natural surface consists of rock or hard clay, the heather can be fixed to it directly. If the natural surface is gravelly, the bottom would also have been covered by boards to which the heather was attached. Portable wooden sluice-boxes were most certainly used in addition to stationary ones.

Pliny writes that the channels are strewn with heather at intervals. This passage is difficult to interpret. The most probable interpretation would be the long channels were lined with heather interspersed with sections without heather. This arrangement would give the water the opportunity to calm down again after having run across the heather and the wooden strips used to fix the heather, both of which create turbulences. Loamy/clayey material, such as the Loipersbach Formation in the *"Karth"*, dissolves very slowly, and the parts of the channel not lined with heather would give this material the chance to settle down before again being swept over more heather. The heather with its small branches and dense leaves is the Roman equivalent of the miners' moss found in a modern sluice-box.

In Greek antiquity, there is evidence that sheepskins were used for gold washing (App. Mithr., 103, (479)). Gold and heavy minerals get caught in the fine hairs of the sheepskin, which were shaken, hung up to dry and shaken again to obtain even the smallest gold particles. Strabo (11, pp.2,19). writes this method of gold washing is the origin of the story of the golden fleece.

When the heather was saturated with black sand, it was removed from the sluice-box, dried and burnt. The ashes were then washed over a bed of grass. Unfortunately Pliny does not describe this process in detail. The reconstruction by López (López, 2005, p.67) of this part of the washing process however makes perfect sense (See Figure 9). The ashes were washed on a wooden

washing table whose lower part was covered by a dense bed of grass cut very short with its roots still attached. The light ashes would get swept away and the heavy gold would get caught in the grass like it does in the mat of a modern sluice box. At the end the grass was removed and shaken so that the gold fell out. It can be assumed with great certainty that this concentrate was then washed in a pan in order to get rid of the last remains of black sand and to obtain the greatest concentration of gold particles possible. Nowadays, in industrial gold washing, mechanical shaker tables are used to separate the gold from other heavy minerals.

The archaeological experiment

After successful gold washing in the brooks of the *"Karth"* with a modern sluice-box we decided to try to reconstruct the method described by Pliny. The aim of the experiment was not a re-enactment, but to prove the efficiency of the Roman method, also to add details not mentioned by Pliny. We used modern materials and tools for the construction of the sluice-box and its operation. Constructing a channel-like sluice-box as described by Pliny would have been a large-scale operation involving digging into the deposit itself and numerous permits would have been needed. Therefore we decided to build a portable wooden sluice-box, as it was most probably also used in Roman times. One of the most important aims was to prove the efficiency of heather, in the same way that miners' moss works today.

Constructing the sluice-box

For the size of our reconstructed sluice-box, we decided to use Roman units of measurements. Accordingly, the length of our sluice-box was 3 metres (~ 10 Roman feet). Its width and the height of the boards at the sides were 30 cm (~ 1 Roman foot) each. The sluice-box was built in two separate halves with a length of 1.5 m each, which were then joined together. Nine boards of a length of 1.5 m, a width of 10 cm, and a thickness of 23 mm were needed for each half (See Figure 10). The bottom and each of the sides consisted of three of these boards screwed tightly together and re-enforced with strips of wood for better stability (See Figure 11). Finally, the sides and the bottom were attached to each other with screws. For better stability, wooden struts were fixed to the top (See Figure 12). In the final step, both parts were tightly joined together with boards at the bottom and the sides. The gaps between the boards were made water-tight with wood putty (See Figure 13).

Inside the lower half of the sluice-box, three wooden strips were fixed to the bottom to prevent the gold not trapped in the heather from being swept away by the water (See Figure 14). The upper end was closed with two boards. This was necessary as we used mechanical pumps in the experiment. About 1 m from the upper end, a hinged wooden flap was fixed to create an opening of 3 cm height above the surface of the box (See Figure 15). This served as a coarse separator that allowed water to pass while preventing large stones from being swept across the heather. As said before, heather is conveniently abundant in the *"Karth"* (See Figure 16). Bunches of heather were bent in a U-shape, and the lower half of the sluice-box was lined with these bunches with the U pointing upstream. The heather was then fixed in place with twigs to prevent it from being swept away by the water (See Figure 17).

The actual experiment

Gold washing with the reconstructed Roman sluice-box

The actual gold washing experiment was carried out in the Tobelbach, a brook running out of the *"Karth*". From previous gold washing activities, we knew that the sediment of this brook contained gold. Four plastic bags of a volume of 50 litres each of heather were collected in the forest. This is

the approximate equivalent of 2 m2 of heather.

Pointed wooden poles of a diameter of 8 cm were attached as legs to each end of the sluice-box in order to support it in the brook. The height of these poles was adjusted so that the sluice-box was mounted at an angle of ~12° (See Figure 18). As the water flow and the gradient of the Tobelbach were very low, water was pumped into the sluice-box by two generator-operated submersible pumps with a maximum capacity of 8000l/h, respectively 9000 l/h. The diameter of the hoses used was 1 inch (2.54 cm). This was to ensure an even and constant supply of water, as would be the case in Roman times. For quality control, to check all the gold was being collected by the heather, a modern sluice-box (See Figure 7) was installed directly below the reconstructed Roman one.

Sediment from the brook was shovelled into buckets of a volume of 12 litres each and poured into the sluice-box (See Figures 19 and 20). Large stones that were stopped by the coarse separator were immediately removed by hand. The sediment that was swept over the heather had to be kept in constant movement by hand, while smaller stones were removed at the same time (See Figure 21). On the morning of the first day of the experiment the heather became saturated after 41 buckets of sediment were fed into the sluice-box. It could no longer retain the black sand and had to be changed. Judging the right moment for changing the heather was easy since saturated heather feels hard to the touch (See Figures 22 and 23). The heather and heavy mineral concentrate were removed from the sluice-box and transferred into two buckets of 15 litres each. The sluice-box was then lined with fresh heather and further 40 buckets of sediment were fed into it. At the end of the first day we had four buckets of heather saturated with gold-bearing heavy mineral concentrate. The heather was then rinsed in a bucket to separate most of the heavy mineral concentrate, which was then washed in a modern sluice-box. By doing this, the one bucketful of material obtained from the Roman sluice-box was reduced by 50% to half a bucket. This concentrate was then washed in a pan to obtain the gold. It can be assumed that the Romans also fed this concentrate again into a sluice-box before further refinement. Additionally, material that had accumulated in the modern quality-control sluice-box was washed in a pan. To our great joy, we did not find even one tiny flake of gold in this material, so we felt sure the heather had done its job.

On the second day of the experiment, the heather was saturated after 44 buckets of sediment had been fed into the sluice-box. Instead of using fresh heather, the saturated heather was rinsed in a bucket filled with water and put back into the sluice-box. A total of 80 buckets of sediment were fed into the sluice-box on the second day. As on the first day, the concentrate was pre-washed in the modern sluice-box, and the heather was put into buckets. Eight buckets containing a volume of 15 litres of heather and sediment were collected during the two days of using the reconstructed Roman sluice-box.

Drying and burning the heather and washing the ashes

After completing work at the brook, the heather was spread out on plastic sheets to dry (See Figure 24). On the third day of the experiment, the semi-dry heather was shaken into buckets to remove any remaining heavy mineral concentrate and was then burnt in a fire bowl (See Figure 25). After 90 minutes, all the heather was reduced to a very fine ash, which was poured into a bucket filled with water.

Next, the heavy mineral concentrate removed from the heather before burning, as well as the concentrate that remained on the plastic sheets, were all washed in a pan. Finally, the ashes were also washed in a pan (See Figure 26). Because the amount of heavy mineral concentrate obtained was relatively small, we skipped the washing over a bed of grass mentioned by Pliny.

Conclusions: The results of the experiment

Reconstructing Roman gold washing as described by Pliny the Elder yielded interesting new insights into the practice of Roman gold washing. These included details not mentioned by Pliny of the construction of stationary and portable sluice-boxes that are necessary for a successful outcome.

First, the wooden strips attached inside the bottom of the sluice-box prevented the gold not trapped in the heather from being swept out of the sluice-box and thereby being lost. Heather cannot be put into the sluice-box any odd way but has to be bent in a U-shape and put into the sluice-box with the U pointing upstream against the current of the water. Thereby a dense carpet of heather was created. The way it was put in with the U pointing upstream insures that the water and sediment can flow evenly across the heather without being impeded by small twigs and branches rising up against the current and thereby catching stones and sand. The heather must be fixed to the sluice-box so that it is not swept away by the water. This could be done with thin strips of wood or twigs. The heather should not cover the whole length of the sluice-box, and the upper end, where water and sediment are fed into the sluice-box, should remain free of heather. The coarse separator flap that we installed is not necessary if large stones are removed before the sediment is fed into the sluice-box, and an even and constant water supply is ensured.

In some of the mining areas in the *"Karth"* there are Roman channels clearly visible, sometimes more than 100 m long. A good example is mining area 6 with 12 parallel channels. These channels could be the stationary sluice-boxes mentioned by Pliny. This theory is supported by the fact that most of these channels lie downhill from large mining pits from which material had clearly been removed, and the channels have a gradient between 10° to 12°, ideal for washing the loamy sediment of the Loipersbach Formation.

It seems our decision to make a portable sluice-box of a length of ten Roman feet was a good one. It can easily be carried and installed by two men, and it can be set up even in difficult terrain. It can be supposed that several of these sluice-boxes were installed one after the other, with the water flowing from one sluice-box to the next.

It also became clear that heather saturated with heavy mineral concentrate can be used numerous times. In the experiment, the carpet of heather had a length of about 1.7 m. After feeding about 40 buckets each holding 12 litres of sediment into the sluice-box the heather had to be changed. Instead of using fresh heather every time, the heather can be rinsed in a bucket and reused. Heather is abundant in the *"Karth"* but considering the size of the Roman mining operations, there would be a problem if fresh heather was used every time it had to be changed. Only when the small leaves, in which gold and heavy minerals get trapped, start to fall off does it need to be changed. Once these small leaves fall off there is nothing left to catch the gold and the washing process becomes inefficient. It is also clear that the heather was rinsed in a bucket before it was burnt. It makes no sense to burn heather while still saturated with heavy minerals and gold. The concentrate collected in buckets was most certainly pre-washed in portable sluice-boxes in order to reduce its volume further. Only then was it washed over a bed of grass together with the ashes of the heather. The grass was then shaken to obtain the gold. Depending on the desired purity of the gold, the material shaken from the bed of grass was finally washed in a pan to remove most of the remaining heavy minerals still mixed with the gold.

Burning the heather showed that even semi-dry heather burned beautifully due to its ethereal oils, and even the woody branches were reduced to very fine ash within 1.5 hours.

A total of 0.132 g of gold was obtained from washing 161 buckets of sediment in the reconstructed Roman sluice-box (See Figure 27). The amount of gold obtained depends not on the efficiency of the reconstructed sluice-box, but on the amount of gold contained in the sediment. Table 1 gives an overview of the input and output of every washing cycle of our two days of experimental gold washing according to Pliny.

	Day 1		**Day 2**	
	Washing cycle 1	Washing cycle 2	Washing cycle 1	Washing cycle 2
Sediment (number of buckets, 12 l each)	41	40	44	36
Heather (number of bags, 50 l each)	1	1	1	
Saturated heather and concentrate (number of buckets 15 l each)	2	2	4	
Sediment (number of buckets, 12 l each)	1		1	
Gold obtained: 0.132 g				

Table 1. An overview of the input and output of every washing cycle of our two days of experimental gold washing according to Pliny.

The experiment showed that an approximation of the gold washing method described by Pliny the Elder is very efficient, and the amount of gold lost is negligible. Even when using a modern sluice-box, it is unavoidable that tiny amounts of gold are lost.

Acknowledgements

First, we thank the Austrian Science Fund for financing the project (project P30790-G25). We are also grateful to Karl Buchleitner, the farmer from the Zisshof, for lending us the generator. Rick Spurway kindly proofread our text. Last but not least, we thank Frank Stremke, our surveyor and cartographer, Viktoria Moser, Daniel Pfeifer, Alexander Sendlhofer, Astrid Stollnberger and Eva Thysell (students at the University of Salzburg) and Simone Elmer (Mining University of Leoben) for their enthusiastic participation in the experiment.

The reconstructed sluice-box was donated to the museum in Neunkirchen, which is the location of the largest and nearest Roman town to the gold mines of the *"Karth".*

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